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No. 1015

THE DEVELOPMENT OF A LATERAL-CONTROL SYSTEM FOR USE WITH LARGE-SPAN FLAPS

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SUMMARY

A spoiler-type lateral-control system has been developed for use on the Northrop P-61 airplane. The lateral-control system is to be used with large-span flaps and consists of a thin circular arc spoiler, linked with a short-span plain aileron located just outboard of the spoiler. This unconventional lateral-control system has been accepted with enthusiasm by the pilots who have flown the airplane. They particularly appreciate its characteristics at high speed. The combination of light forces, favorable yawing moment, and low wing torsional moments, make it a very effective, easily applied control. The control available at and through the stall is also remarkably good, although this characteristic may be attributed, in part, to an exceptionally good wing stalling pattern rather than entirely to the use of the spoiler-type aileron. In the landing configuration, the lateral-control effectiveness increases automatically with the extension of wing flaps so that powerful control is available during the approach. There is, however, a decrease in effectiveness for the first 5 percent of the wheel travel with a resultant tendency for inexperienced pilots to overcontrol slightly at low speeds. The fact that the aileron can be fully used at the stall, however, more than compensates for this loss of effectiveness with flaps down and greatly enhances the airplane's landing performance.

INTRODUCTION

The trend toward the employment of ever-increasing wing loadings, desirable from the standpoint of high-speed performance, has necessarily worked against the maintenance of

low airplane landing speeds. In addition, increasing requirements for lateral control have limited the spanwise extent of the wing flap (which is, in many cases, cut up by large, well-faired engine nacelles) so that the attainment of a landing speed, for a high-performance aircraft, of, say, 80 miles per hour is no small accomplishment. In most cases the problem is "solved" by filling the available wing span with a flap of convenient chord and suffering the consequences as regards landing speed. This quasi solution will not do in designs where landing performance is deemed of great importance, and it then becomes necessary for the designer to employ partial-span flaps of improved quality: namely, multiple-slotted flap, slotted plus split flap, Fowler flap, and so forth (see reference 1); or in extreme cases to devise ways and means of utilizing the wing span normally devoted to ailerons. Both the above-mentioned possibilities have been the subject of considerable wind-tunnel and flight testing, the results of which have indicated that the latter treatment, while obviously giving better results from the standpoint of maximum lift, is fraught with many and varied difficulties as regards lateral control - a drawback obviously not applying to the first solution.

In the case of a recent Northrop design (figs. 1 and 2), landing and approach performance were deemed of sufficient importance to warrant an attempted solution of the full-span-flap problem. The choice of the lateral control arrangement to be used was largely a matter of picking the lesser of a number of evils, in view of the limited success of installations and schemes tested up to that time. A review of the possibilities, however, showed that, as regards adequacy of control, and mechanical simplicity, the spoiler-type lateral control device had the advantage over slot-lip ailerons, drooped ailerons, plain ailerons in combination with retractable flaps, or any of the other devices enjoying current favor. As a matter of fact, the only question mark concerning its successful application to an airplane was its very erratic hinge moments - a fault also appearing in some of the other possible systems. Accordingly, the retractable aileron was chosen as the most likely to succeed. The ways and means used in obtaining satisfactory hinge moments and effectiveness are given herein.

SYMBOLS

$C_{h'}$ scoop hinge-moment coefficient, $H/qb'tr$

b' scoop span

t width of scoop edge

r scoop radius

C_l rolling-moment coefficient

C_h balance aileron hinge-moment coefficient, $H/qS\bar{c}$

H hinge moment of control surface

S area aft of hinge line

$\bar{c}$ average chord aft of hinge

δ_a balance aileron deflection, positive downward

δ_s scoop deflection, positive downward

w wheel angle

b wing span

c local wing chord

P total tangential wheel force

l wheel radius

$pb/2V$ steady state wing tip helix angle

p rate of roll

V airplane forward velocity

k control-surface effectiveness, $\left(\frac{\partial \alpha}{\partial \delta}\right)$ for constant section lift coefficient

q dynamic pressure, $\frac{1}{2}\rho V^2$

ρ mass density of air

$$C_{h_\delta} = \frac{\partial C_h}{\partial \delta_a}$$

$$C_{l_p} = \frac{\partial C_l}{\partial (pb/2V)}$$

Subscripts

u upgoing surface

l downgoing surface

DESIGN CALCULATIONS

General.- It soon became apparent that the solution of the hinge-moment problem would be perhaps the most difficult. Researches conducted by the National Advisory Committee for Aeronautics (reference 2) finally had produced a stable hinge-moment variation for a modified circular-arc spoiler, but only through the use of various vanes, vents, and passages, some of them apparently quite critical. Even then, the resultant pilot forces were inacceptably high, and no satisfactory method of trim control was available. Preliminary tests in the Northrop wind tunnel, directed toward the possibility of obtaining stable hinge moments with a system in which the center of rotation and the center of the arc were not coincident, showed no promise; pressure measurements corroborated the speculation that the extending hinge moments, existing near the flush neutral position were due to the negative pressures acting on the exposed edge of the scoop.[1] (These extending moments, when combined in an unsymmetrical mechanical system, produce unstable pilot forces.) While these extending moments were not directly proportional to the upper-surface of the scoop, nevertheless their magnitude could apparently be greatly decreased by a reduction of this area, as shown in the tests of reference 2. It was decided, accordingly, to minimize the inherent instability of the scoop by the simple expedient of reducing its thickness as much as possible. Calculations, assuming the scoop hinge moments to be

[1]The term "scoop" will hereafter be used to denote a circular-arc retractable aileron in preference to the word "spoiler," which connotes a device capable only of one-way action and thus relatively ineffective on a wing already at negative lift.

proportional to the product of scoop radius and upper-surface area, showed that the contribution of a 1/4-inch-thick scoop would be quite negligible compared to the allowable hinge moment.

It was thus possible to provide lateral control with very little attendant pilot effort, and there remained only to build into the system a positive centering tendency, some means of trim control, and some degree of pilot "feel." Since these properties are all, of course, available in the conventional lateral control, one solution of the difficulties enumerated was to link to the scoop system a complete conventional aileron of small span. This compromise system, moreover, consisted of components the characteristics of which were sufficiently explored to allow of routine aerodynamic calculations. Its advantages more than outweighed the loss of wing flap attending the use of a small conventional aileron. There now existed a reasonable certainty that a 90-percent full-span flap, say, could be made to work with a relatively small amount of development time.

In the interests of a continuous wing flap and also as a concession to conservatism, it was decided to locate the conventional "balance" aileron at the wing tip. A preliminary wheel-force analysis, neglecting the scoop contribution, indicated that a plain-flap aileron occupying the outer wing bay,[1] having a chord of approximately 15 percent of the wing chord and a maximum throw of $\pm 25^\circ$, would supply forces in the neighborhood of 80 pounds wheel force at 80 percent of maximum indicated level flight speed. (See reference 3.) The scoop located adjacent to the balance aileron and at approximately 70 percent wing chord, to insure acceptable time-lag characteristics, was laid out, in accordance with the data of references 2, 4, and 5 and the method of reference 6, to give a $pb/2V = 0.07$ in combination with the balance aileron. Detailed calculations for the final configuration are presented below to illustrate the methods employed.

Rolling moment.- The effective section twist (k_s) due to the scoop projection above the wing surface was obtained by comparing the rolling moments due to scoops (reference 2) with those due to a conventional aileron (reference 7) occupying the same span on a geometrically similar wing. The experimentally determined effectiveness of the conventional aileron

[1]Layout of the component parts of the lateral control system was already limited by detailed structural design, which it was not expedient to change.

was made the basis of the calculation, thus using the equation

$$C_l = 1/k \quad \partial C_l/\partial \delta_a \; (k\delta_a)$$

and substituting the value of the effectiveness $\partial C_l/\partial \delta_a$ obtained for the plain aileron and the known value of k for a 15-percent chord plain flap (reference 4) $C_l = -0.0016/0.38 \; (k\delta^\circ) = -0.0042 \; (k\delta^\circ)$, whereby the rolling moment is related to the section twist for the given plan form. The scoop rolling moments are transformed, with this equation, to values of effective twist ($k\delta$). The results thus obtained are plotted as the dashed and broken lines in figure 3; they compare favorably with unpublished Northrop section data (full-line) if correction for chordwise location is made using the results of reference 8. While the proposed installation was to incorporate a slot behind the scoop for the purpose of improving the lateral control, it was apparent that at low values of the wing lift coefficient, the net effect of the slot was quite small (see fig. 3); and it would be conservative to use the section data at zero lift for design calculations made in accordance with the methods of reference 6. The balance-aileron rolling moments, computed in the same way, with no regard for possible interference effects were added directly to the scoop contribution to give the total rolling moment.

The geometry and rolling-moment calculations for the P-61 are presented below:

Scoop

Chordwise location	0.72c	
Location of inboard end	$0.49 \frac{b}{2}$	$C_{l_\delta}/k = 0.360$
Location of outboard end	$0.83 \frac{b}{2}$	
Max. scoop extension (inboard)	0.075c	
Max. scoop extension (outboard)	0.080c	

Aileron

Type: plain flap, sealed gap

Location of inboard end	$0.83 \frac{b}{2}$	$C_{l_\delta}/k = 0.105$
Location of outboard end	$0.94 \frac{b}{2}$	
Chord aft of hinge line	0.17c	
Max. deflection	$\pm 22^\circ$	

(C_{l_δ}/k are from reference 6 for A.R. 6.0 and $\lambda = 0.50$ and antisymmetrical aileron deflection. C_{l_δ} denotes $\partial C_l/\partial \delta_a$.)

For the average maximum scoop extension of 0.077c, the corresponding effectiveness is $k\delta = 7.6^\circ$ (fig. 3). For the aileron, the data of reference 5 gives $k\delta = 22 \times 0.27 = 6^\circ$, which corresponds to 15° of fully effective travel at the wind tunnel value of k shown in reference 4. The maximum rolling moment coefficient at low lift coefficients is thus:

$$C_l = 0.360 \times 7.6/2 \times 57.3 + 0.105 \times 6/57.3 = 0.0348$$

This value was never checked on a complete wind-tunnel model, but similar calculations made for the wing-scoop geometry of the tests of reference 9 which became available at a later date, agree, within 5 percent, with the experimental results.

Hinge moments.- Hinge-moment measurements available for a plate-type scoop have been reduced to coefficient form in figure 4. The data, reduced on the basis of the spoiler radius and edge area, show little consistency in either test conditions or resulting hinge-moment coefficients. A consistent variation of spoiler opening hinge moment with lift coefficient, as found in reference 2, is not sufficient to bring the curves into agreement, nor are the theoretical upper-surface pressures, scoop retracted, any indication of the measured opening hinge moments. For the P-61 design the data most directly applicable (unpublished Northrop data) were used. Balance-aileron hinge moments were assumed linear and estimated, from the available data, to correspond to $C_{h_\delta} = -0.009$, including the reduction due to the response effect.[1]

[1]The effect of angle of attack change due to rolling velocity.

With these data, the geometric relationships of figure 5, and the dimensions of the controls ($S\bar{c}$ = 5.88, $tb'r$ = 0.19 ft^3), the total wheel force was calculated for an indicated speed of 258 miles per hour, using the equation:

$$P_l = qtb'r\left[C_{h'_u}(d\delta_s/dw)_u + C_{h'_l}(d\delta_s/dw)_l\right] + 2qS\bar{c}\,C_{h_\delta}\,\delta_a\,d\delta_a/dw$$

The last term corresponds to the balance aileron contribution and is doubled because of the symmetry of the control system.

The results of this calculation are plotted in figure 6, where the spoiler contribution is seen to be quite negligible, provided a minimum gap is maintained. The possibility of overbalance near the neutral wheel position is illustrated by the case of the 0.004c gap. It was clear that small changes in the geometry, especially if they included an increase in spoiler thickness, could easily result in an unstable region near neutral. Since the magnitude of the unstable scoop contribution appeared largely unpredictable because of possible structural deflections, scale effect, or aerodynamic interference, a large balance tab (also used for trim) with adjustments for positive or negative boost was incorporated in the balance-aileron design. In this way, the balance-aileron contribution could be adjusted by flight test to be just sufficient to overcome the unstable scoop, a condition obviously giving the lowest acceptable pilot forces. Further, it was decided to resist strenuously any compromise with structural weight requirements which might increase the effective thickness of the scoop, since the success of the combined system might depend on this point.

Air loads.- In order to obtain the minimum allowable scoop thickness, accurate air load information was required. The data plotted in figure 7, show that the relative load distribution is independent of scoop deflection and the magnitude of the load is approximately proportional to this deflection. Since desirable wheel forces do not exceed 80 pounds at 80 percent of maximum indicated speed in level flight, it is physically possible for the pilot to obtain full wheel throw at very high speeds. In the present application, the scoop design condition was taken to correspond to full extension in a dive. Deflection of the control system, which would tend to reduce the available scoop extension, was neglected. Static structural tests showed that a 1/4-inch magnesium plate, formed to the proper contour and incorporating heliarc-welded hinge brackets, would take the design load thus determined. So far, the basic

requirements for a successful lateral control of the type under discussion offered little difficulty. Some further details and conjectures that went into the complete design are discussed below.

Scoop geometry.- The scoop-flap section geometry was patterned rather closely after the configurations investigated by the NACA in their spoiler-slot plus slotted-flap investigation. (See reference 2.) A rather blunt slotted-flap of approximately 25-percent chord was supported at three points in the outer wing and actuated through a four-bar linkage which gave approximately the optimum flap-slot configuration for the important flap positions. (See reference 1.) The scoop was placed just forward of the flap and hinged as near the intersection of the rear spar and wing mold lines as structure and torque-tube size would allow. The scoop radius was determined by the requirement that the down-travel of the scoop be at least 40 percent of the up-travel, but that its maximum vertical projection below the wing be limited as much as possible. The latter requirement, it was thought, would minimize any adverse effects due to down deflection; the first requirement would permit approximately linear scoop extension with wheel angle - a requisite of effective control near neutral - without the high acceleration (and the accompanying "hard-spot") that would result from a large differential motion. The slot behind the scoop was made a constant width of approximately 1/2 inch, except for the lip which was brought as close to the scoop as possible, and left uncovered at all times. The drag penalty thus incurred, it was thought, would be little larger than that associated with an unsealed trailing-edge flap, and the alternative - to incorporate a plate along the upper edge of the scoop, which would seal the slot for neutral and downward scoop deflections - would drastically change the nature and magnitude of the scoop hinge moments.

The final section geometry is shown in figure 8. It should be mentioned that for the maximum extension of 65° the lower edge of the scoop is above the upper wing surface by approximately 1 inch. As indicated in reference 2, there is no change in effectiveness with such an emergence of the scoop.

Flutter considerations.- The scoop was dynamically balanced about its hinge line and the nacelle centerline by a linked counterweight; the balance aileron was statically balanced about its hinge line by two attached weights. The purpose of these precautions, of course, was to prevent the occurrence of wing-aileron flutter within the flying range of the airplane. Later flutter calculations, using data available

from ground vibration tests, indicated that the fairly complicated scoop counterweight could be eliminated by overbalancing the balance aileron, provided the linkage between it and the scoop were very rigid. In making such calculations and also in estimating aileron reversal speed, it was necessary to know the section pitching moments due to a scoop. These were deduced from the data of reference 8 and are shown plotted in figure 9 in the form of center-of-pressure location. Assuming the elastic axis to coincide with the wing quarter-chord point, these data indicate that, for a scoop located at 72-percent chord, the wing torsional moments due to the scoop extension are approximately two-fifths of the moments due to the deflection of an equally effective trailing-edge flap. This means that for a given wing rigidity the reversal speed of a scoop control is about 60 percent higher than that of a conventional control. If the elastic axis is farther aft, the degree of improvement is even greater.

Preflight changes.- When the system was completely installed in the airplane, it was noted that rapid manipulation of the control wheel on the ground produced an appreciable lag in the scoop motion because of the combined inertia and flexibility of the system. To remedy this, the scoop torque tube, which had been designed to strength requirements only, was greatly stiffened, and, in addition, the inertia of the scoop was lowered by drilling out enough 3/4-inch holes to reduce its weight approximately 20 percent. (See fig. 8.) A rough check in the Northrop wind tunnel indicated that the loss in effectiveness due to a 30-percent area reduction, by means of uniformly spaced holes, would be approximately 15 percent. (This result is in good agreement with measurements of the effect of perforations on split flaps. (See reference 10.) To prevent the 10-percent loss corresponding to the actual perforations. (20-percent area reduction), the scoop was fabric covered.

Flight tests.- Preliminary flight tests of the new lateral-control arrangement showed it to be generally satisfactory from the standpoint of lateral-control forces and response. Unfortunately, however, inspection of the scoop and slot structure after each landing indicated that serious mechanical interference was occurring during flight. This interference manifested itself primarily in repeated failure of the lower slot lip which was progressively strengthened, and in abrasion of the fabric scoop covering. It was deduced from this evidence that, under the influence of air flow through the slot, the scoop was vibrating quite violently, and, accordingly, steps were taken to determine the conditions and modes

of vibration. Electrical strain-gage pickups were cemented to the lip, the hinge brackets, and the scoop, which was left uncovered for ease of inspection, and their responses were observed in flight through use of an oscilloscope. These observations showed that above a relatively low airspeed the scoop vibrated quite violently in a chordwise direction with nodes at each of the hinge brackets, the amplitude of vibration being apparently limited by contact with the slot walls. These vibrations were not felt by the pilot at any time, presumably because they included no vertical or rotational components. It was believed that these vibrations were the result of air flow through the slot, a fact later substantiated and reported in appendix I. In order to eliminate all flow through the slot, a fairing strip covering the lower opening was attached to the bottom of the wing. (See figs. 10a and 10b.) This expedient was immediately successful in eliminating all signs of vibration, and contrary to expectations was, in the pilot's opinion, not appreciably detrimental to the effectiveness with flaps up, even for small displacements of the perforated scoop. (The fabric cover had by now been discarded to facilitate production and maintenance.) The effect of the slot cover on airplane performance was expected, if anything, to be slightly beneficial, since the fairing was located in a rather noncritical spot on the wing, and it eliminated air flow losses through the slot. It remained now to determine, quantitatively, the characteristics of the revised arrangement prior to final acceptance.

Before this could be done, however, another problem arose in connection with the approach and landing configurations. It was found, with the wing flaps full down and regardless of the power setting, that the airplane's lateral behavior was unsatisfactory; pilots who flew the craft complained of difficulty in controlling the airplane in rough air. Wind-tunnel tests had shown no change in effective dihedral with flap setting for the power-off condition, and since further flight investigation revealed a "dead spot," or region of poor effectiveness in the lateral control near neutral, it was concluded that herein lay the difficulty. During the flight investigations leading to this conclusion, it was discovered that sealing the outboard flap slot with a metal plate improved the lateral control and had a minor effect on maximum lift. This result was verified by further tests made with a more practical cloth seal (figs. 10a and 10b), wherein the stalling characteristics were fully investigated and found to be essentially unchanged. (See fig. 11.) The large effect of the flap-slot seal on the lateral control and its negligible effect on lift characteristics are not yet fully understood; further research

on the problem, which has thus been solved practically but remains unexplained theoretically, has been temporarily postponed. It is believed, however, that the effect of the flap slot on lateral control is due to the fact that a small scoop extension augments the flow through the flap slot, thereby increasing the lift and counteracting the intended effect of the original control deflection.

Examples of the rolling-velocity data obtained in flight are shown in figures 12 to 18 wherein the wing-tip helix angle, $pb/2V$, corresponding to equilibrium rate of roll is plotted against scoop extension in percent of wing chord. The data show that, with the flap retracted, the scoop slot is not required to produce an essentially linear variation of rolling velocity with scoop extension. Also, the control effectiveness remains practically constant for all the angles of attack tested. It must be remembered, however, that these curves of $pb/2V$ versus scoop deflection include the component contributed by the "balance" aileron. There is thus no necessary disagreement between these data and those of references 2 and 11 which indicate respectively that, for a pure scoop system, the slot is required for linear control and that the effectiveness decreases with increasing lift coefficient. At any rate, the rolling-moment characteristics exhibited here are practically ideal, $pb/2V$ being directly proportional to the scoop extension, only, and having a maximum value slightly greater than that calculated.[1] The effectiveness in inverted flight has been found to be very good - a result that surprises those who erroneously consider the control a "spoiler" in the true sense of the word.

The original "dead spot" in the control effectiveness with flaps down and scoop closed, is shown in figures 15 and 16, the extent of the ineffective region covering approximately 20 percent of full travel. Reference to the same figures will show that the effect of sealing the flap slot is to eliminate this region of poor control almost entirely. A further increase in effectiveness is obtained by opening the scoop slot, as indicated in figures 17 and 18. These results are all in good agreement with the original speculations as to the cause of the "dead spot" and indicate that a completely effective roll control could be obtained with both flap slot and scoop slot open. This possibility, however, was discarded from a

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[1] Taking C_{l_p}, the damping in roll, equal to 0.45 from reference 6 and reducing the calculated scoop effectiveness by 10 percent for perforations $pb/2V = 0.0324/0.45 = 0.072$.

practical standpoint, since a method to prevent vibration with the open slot was not immediately evident; whereas the scoop-slot cover and flap-slot seal could be readily applied to the airplane with apparently no deleterious effects on the stall, and without seriously limiting the available lateral control.

The final configuration, embodying a perforated scoop, scoop-slot cover, flap-slot seal, and zero aileron-boost tab was flight checked to determine the magnitude of the control forces. The results of these flights are shown in figure 19, where, neglecting an appreciable scatter, it may be noted that the pilot force varies approximately linearly with scoop extension and dynamic pressure. Interpolating for a speed of 258 miles per hour indicated, the force corresponding to a maximum scoop deflection of 7.7 percent is read at 82 pounds, a value in close agreement with that calculated for this speed. The forces required for lateral control may here be seen to be relatively small for an airplane in this class. As a matter of fact, the forces required for lateral trim, even under single engine operation, are so light, that it has been found feasible to eliminate, entirely, the aileron tab.

CONCLUDING REMARKS

1. The results of this development program indicate, to some degree, the success obtained with this new lateral-control arrangement. Another indication is the universal enthusiasm with which pilots have accepted this unconventional control. They particularly appreciate its characteristics at high speed. The combination of light forces, favorable yawing moment, and low wing torsional moments, make it a very effective, easily applied control. The control available at and through the stall is also remarkably good, although this characteristic may be attributed, in part, to an exceptionally good wing stalling pattern rather than entirely to the use of the spoiler-type aileron. In the landing configuration, the lateral-control effectiveness increases automatically with the extension of wing flaps so that powerful control is available during the approach. There is, however, a decrease in effectiveness for the first 5 percent of the wheel travel with a resultant tendency for inexperienced pilots to over-control slightly at low speeds. The fact that the aileron can be fully used at the stall, however, more than compensates for this loss of effectiveness with flaps down and greatly enhances the airplane's landing performance.

2. The scoop vibration that occurred inside the slot during the preliminary flight tests can be eliminated by closing the lower-surface slot. Closing the slot had little effect on the control flaps up, but with flaps down, the effect was detrimental unless the flap slot was sealed.

3. The important aerodynamic characteristics of the system - control effectiveness and pilot forces - have been calculated with sufficient accuracy to make the application one of routine aerodynamic computation. It is believed that the use of methods presented will give satisfactory results for the aerodynamic design of spoiler-type lateral-control systems.

Northrop Aircraft Corporation
Hawthorne, Calif., October 31, 1945.

APPENDIX I

SCOOP VIBRATION TESTS

In order to determine the cause of and to eliminate the severe chordwise scoop vibration encountered in flight tests of the P-61 airplane at all speeds in excess of 140 miles per hour, a full-size wooden mock-up of the airplane outer wing panel, equipped with a production scoop, was tested in the Northrop wind-tunnel building. The maximum velocity through the slot was equivalent to a dynamic pressure of about 11 inches of water, and was obtained by the use of a Rees blower which was connected to the under surface of the wing by a series of canvas ducts. The static pressure in the bag below the scoop was equivalent to a height of 17.5 inches of water. These pressures remained fairly constant throughout the tests. Scoop vibration frequencies were measured with a strobotac, while vibration amplitude was measured with a marker plate in contact with a marker attached to the upper edge of the spoiler. During the first few tests, it became apparent that the scoop vibrations were very sensitive to duct characteristics. At first, the main duct from the blower was attached to the scoop duct by means of a square wooden frame but it was thought that this entrance to the scoop duct was causing some interference with the flow, so a cylindrical sheet metal section was substituted for the wooden frame. This new

arrangement made a marked difference in the vibration characteristics.

With the scoop deflected up 30°, vibrations of 5000 cycles per minute and amplitudes of 1¼ inches were measured, and it was impossible to stop these vibrations by any mechanical means such as rollers, felt pads, or guides in contact with the scoop either in the scoop slot or above the wing. With the scoop fully deflected and completely out of the wing, it was possible to stop the vibrations with a rubber-roller damper mounted above the wing and in contact with the front scoop face. Then various aerodynamic means were tried to control the scoop vibrations; these means consisted of spanwise strips of felt seal in the scoop slot, metal vanes to deflect the air flow off the rear face of the spoiler, spring loaded doors to seal off the flow through the scoop slot when the scoop was completely out of the wing, small spoilers attached to the leading and trailing edges of the scoop aileron, an auxiliary slot in the wing mock-up behind the scoop aileron, variation of the scoop slot gap at the lower surface of the wing mock-up, various degrees of roughness applied to the rear scoop face, and spanwise grooves machined in the rear scoop face. The auxiliary slot eliminated scoop vibrations at all deflections; spanwise roughness strips of thin string or tubing applied to the rear scoop face almost entirely prevented vibrations; and coarse sand or cork roughness sprinkled on lacquer over the lower 40 percent of the scoop rear face entirely eliminated vibrations except with the scoop completely out of the wing mock-up, where a rubber roller contacting the scoop easily damped the vibrations. All other means tested proved to be partially or entirely unsuccessful in eliminating the vibration.

Subsequent tests on the same setup, with a strain gage installed on the front and rear faces of the scoop near its top edge at the center of the unsupported span between the outboard supports indicated violent vibrations of the scoop in its original condition and no vibrations when the rear scoop face was roughened.

Three flight tests were then made with the P-61A airplane which had the right-hand scoop slot open, right-hand scoop roughened with cork in lacquer, and strain gages attached to the inboard scoop halfway between supports at the top edge. Strain-gage and oscillograph readings were calibrated approximately by means of ground vibration tests before flight. Results of these flight tests indicated no vibrations at speeds below 275 miles per hour in the cruising configuration with

the scoop in neutral and deflected up and down. At speeds of 275, 300, 325, and 350 miles per hour, cruising configuration, and at speeds of 140 and 160 miles per hour, flaps fully depressed, low-frequency vibrations of about 1100 cycles per minute were encountered, which were sometimes spasmodic. At 350 miles per hour, the amplitude of vibration with the scoop neutral was about 3/16 inch. On one of the flights, vibrations of the order of 400 cycles per minute with an amplitude of less than 1/16 inch were encountered at a speed of 335 miles per hour.

Comparison of these flight test results with the vibration test results obtained with the scoop in the original condition shows that roughening the rear scoop face had a very favorable effect in raising the speed at which vibration was encountered.

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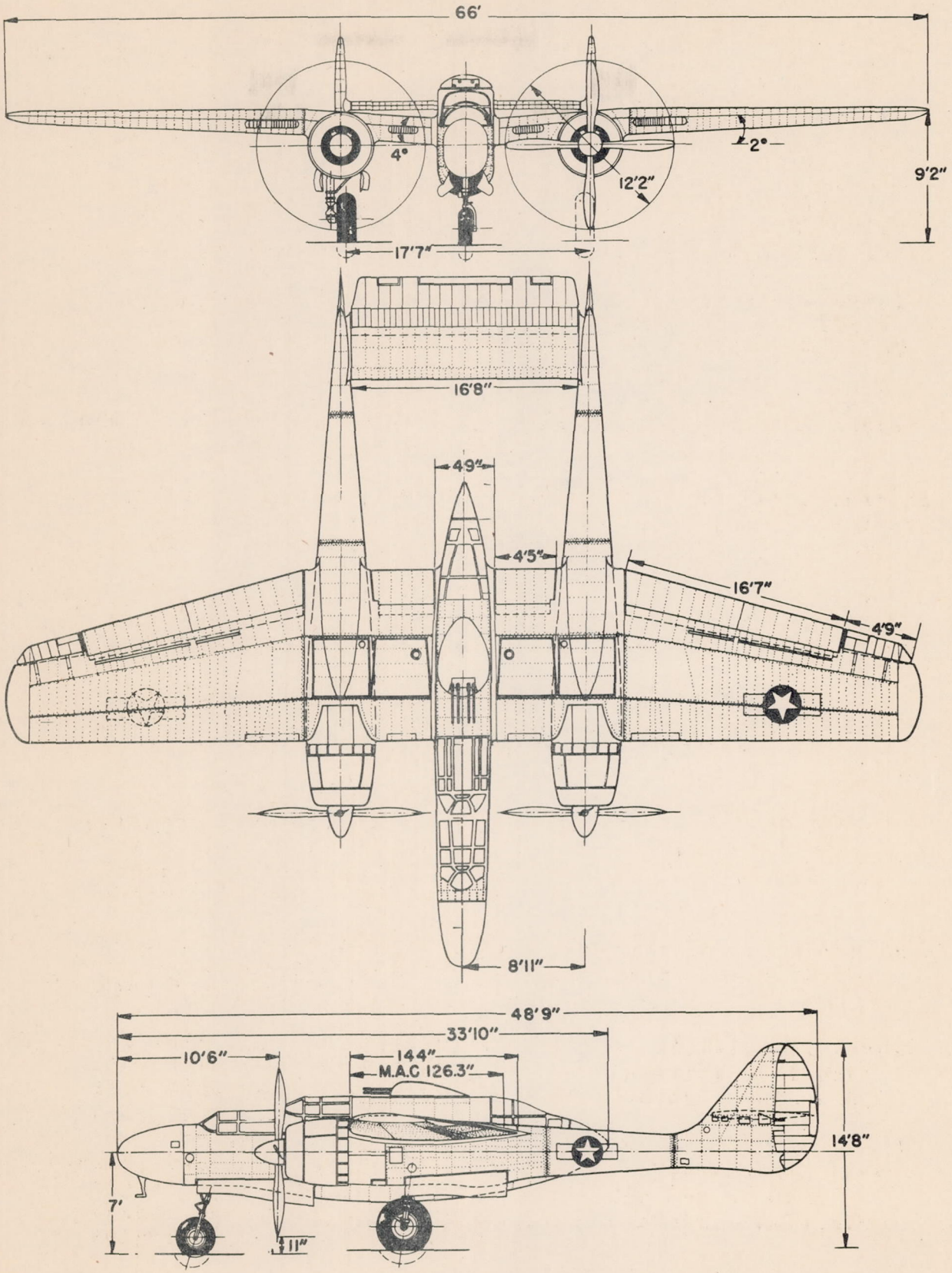


Figure 1.- Three view drawing of Northop P-61 airplane.

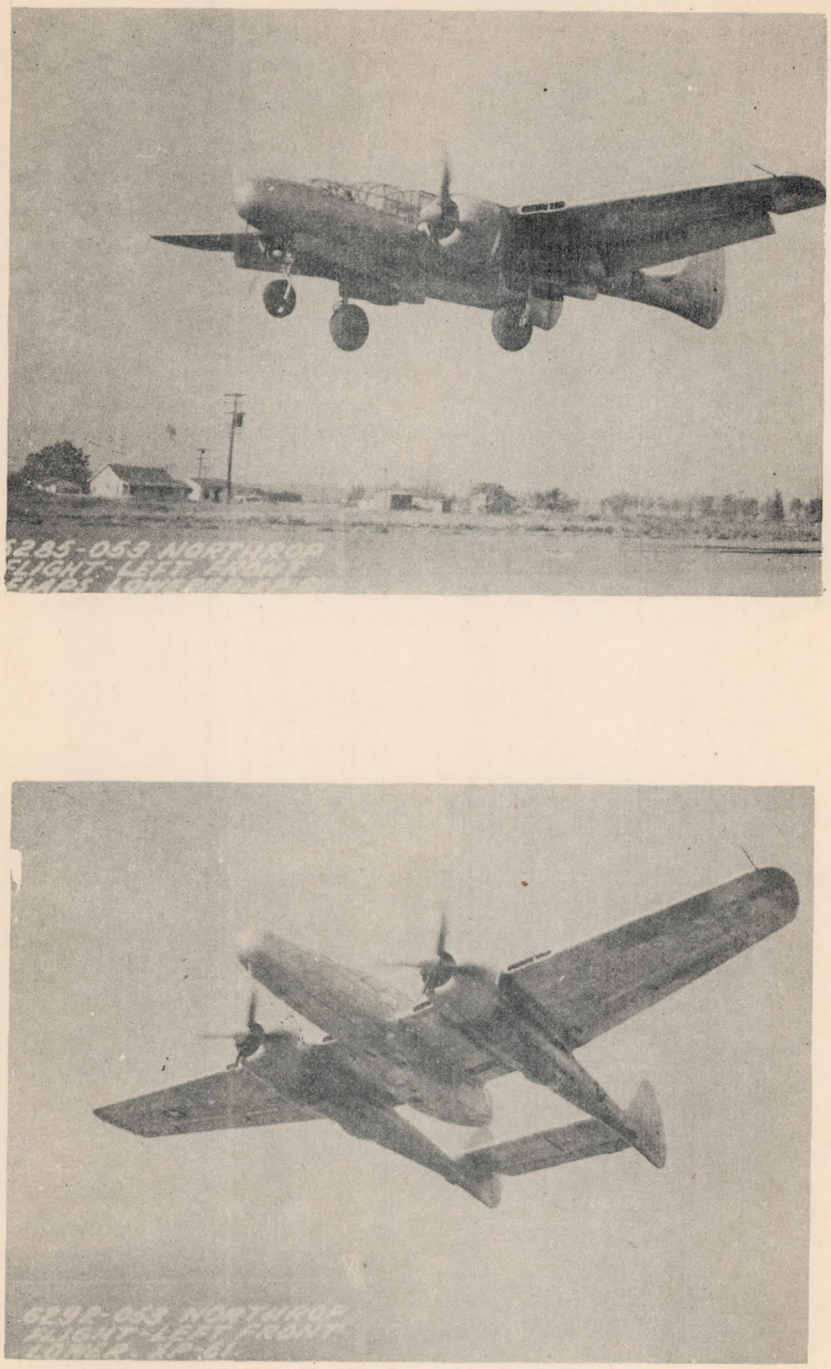


Figure 2.- Photographs of the Northrop XP-61 airplane in flight.

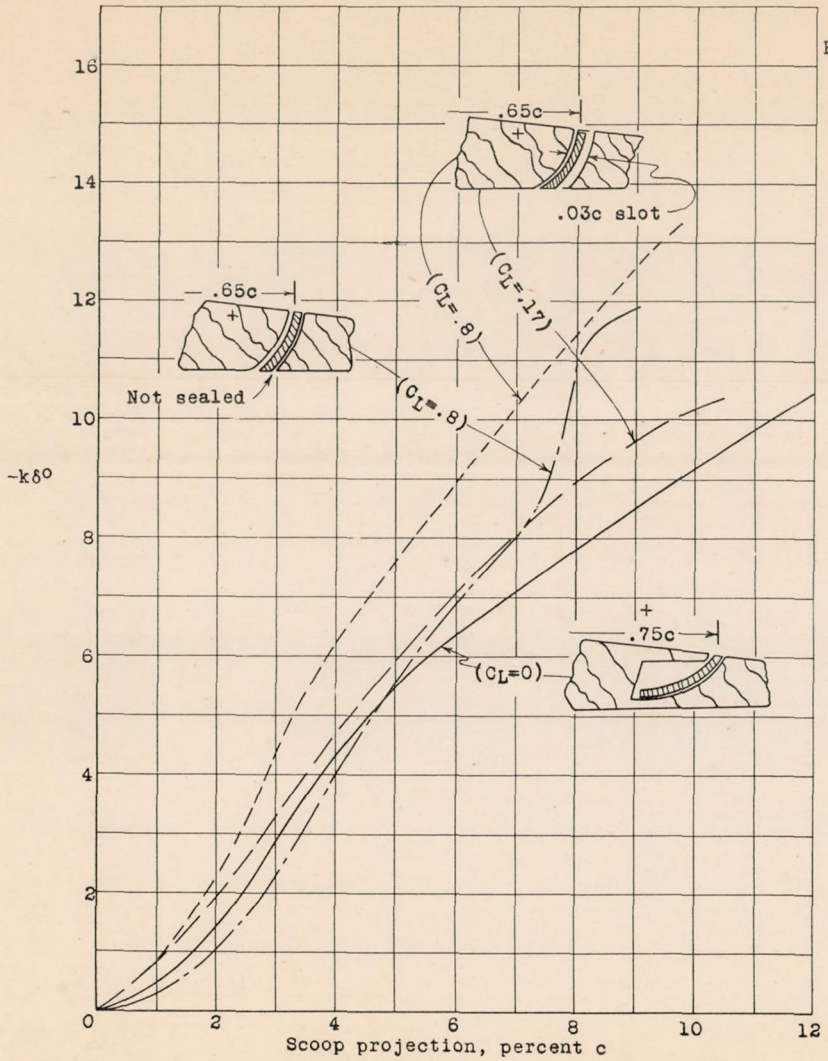
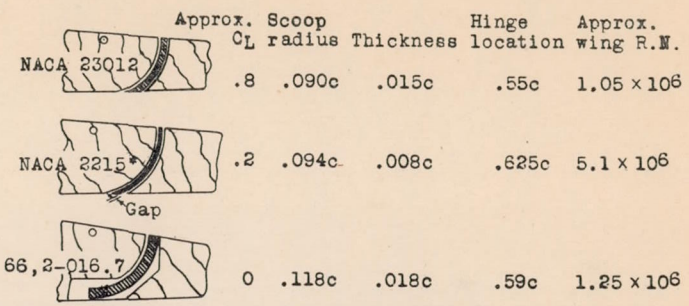


Figure 3.- Scoop effectiveness with flaps retracted.



* Approximate profile-exact section is zap, 15 percent thick

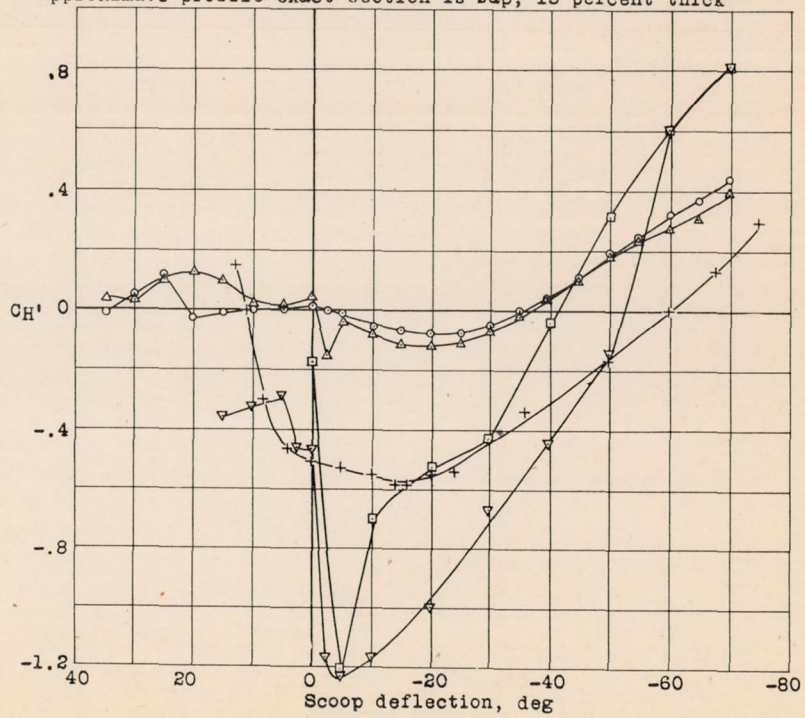


Figure 4.- Scoop hinge-moments with flaps retracted.

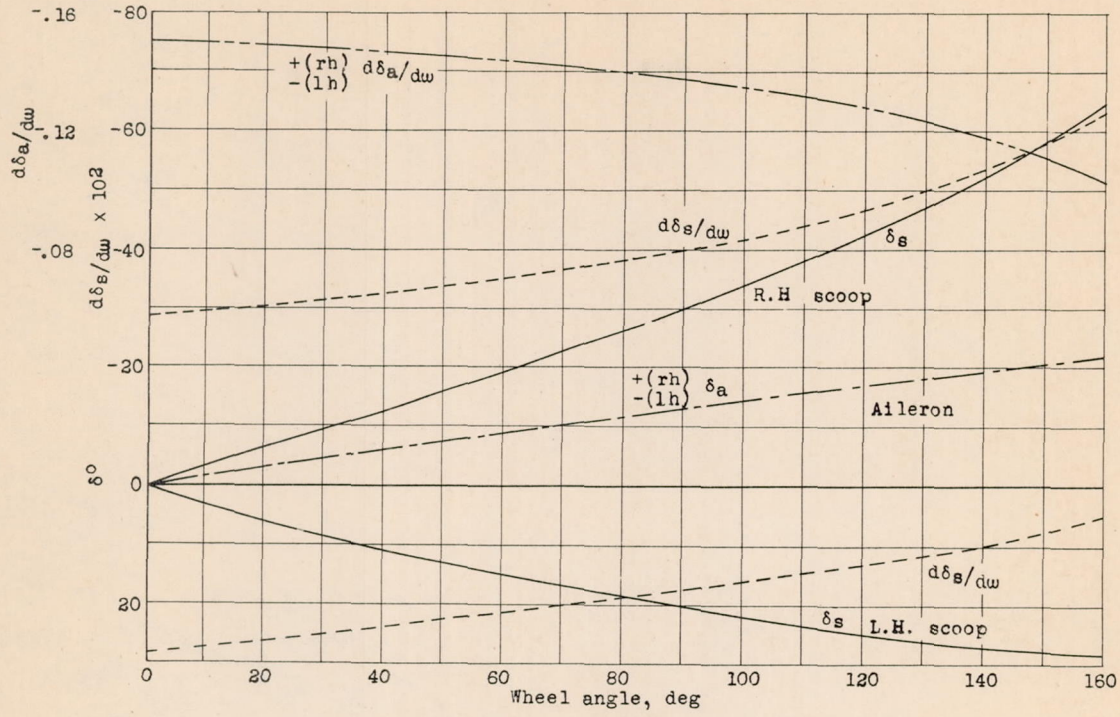


Figure 5.- Control system geometry.

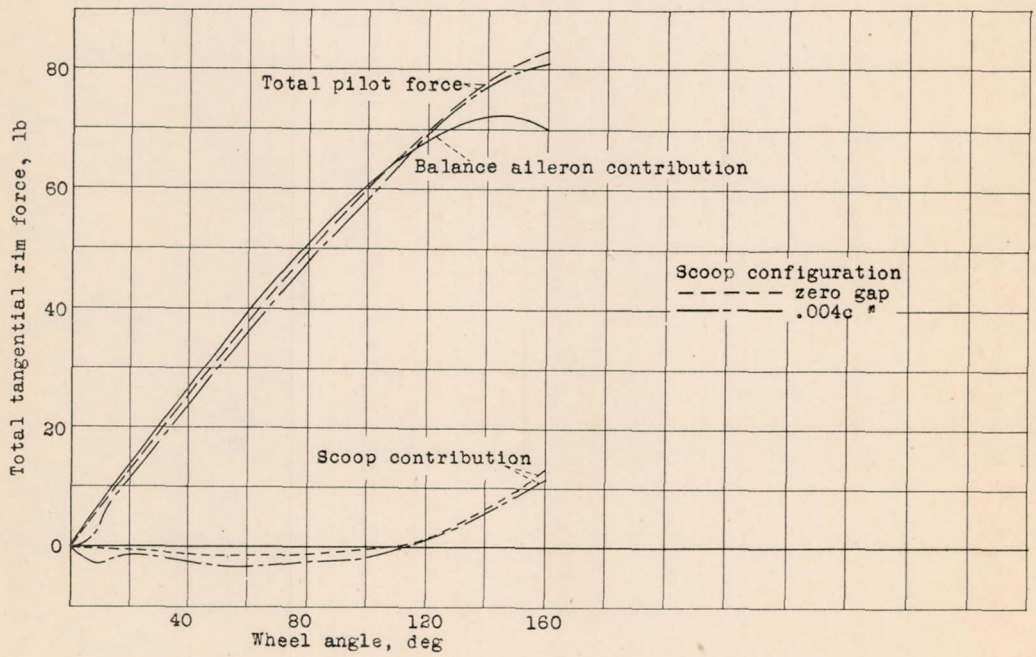


Figure 6.- Pilot-force curves.

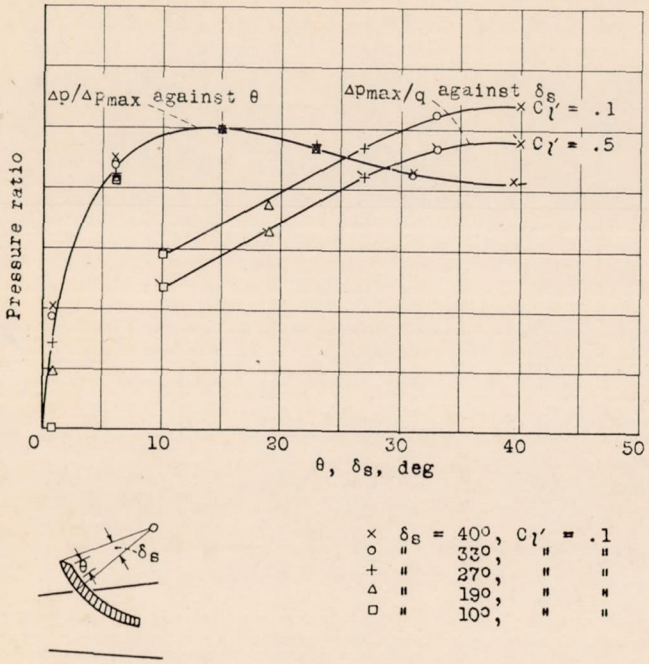
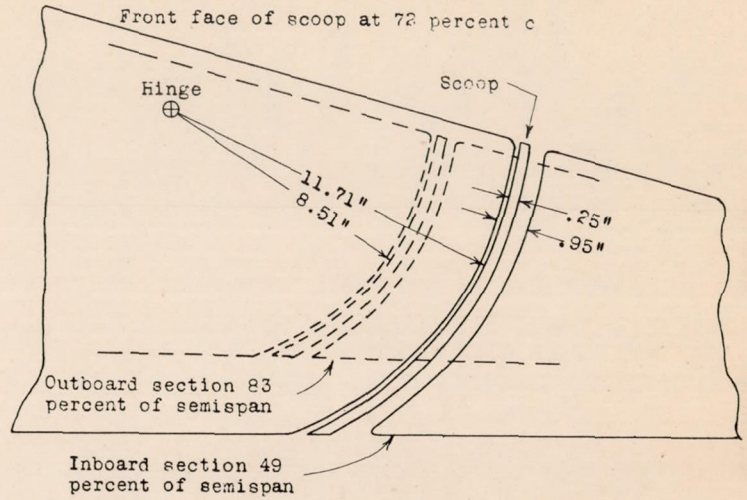


Figure 7.- Pressure distribution over scoop.



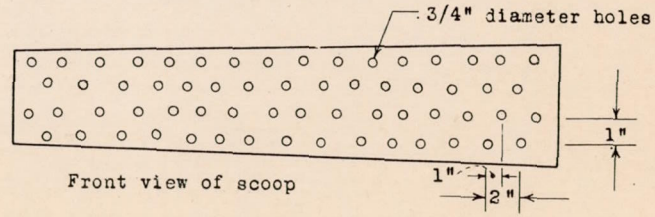


Figure 8.- Scoop geometry.

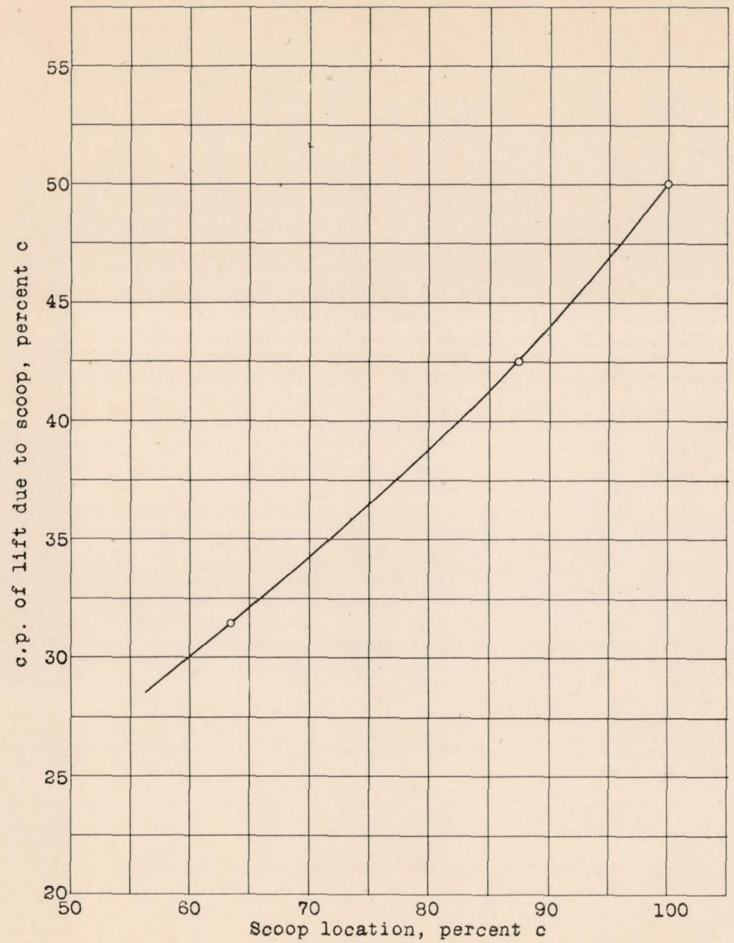


Figure 9.- Center of pressure of scoop lift at $\alpha = 0^{\circ}$.

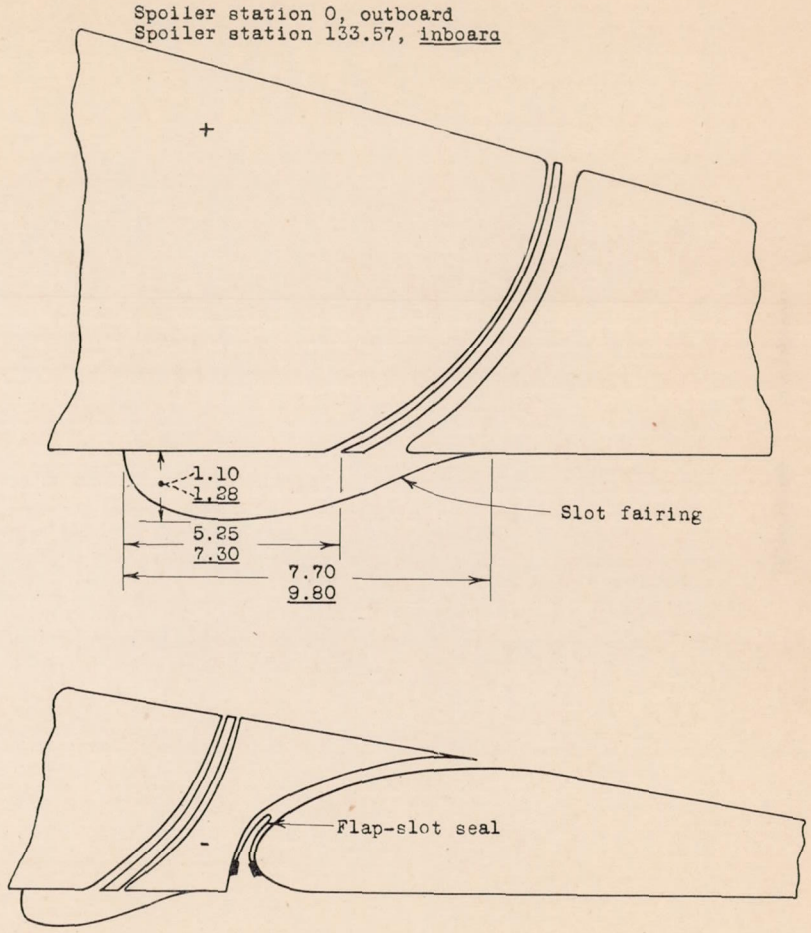


Figure 10a.- Details of scoop slot fairing and the flap-slot seal.

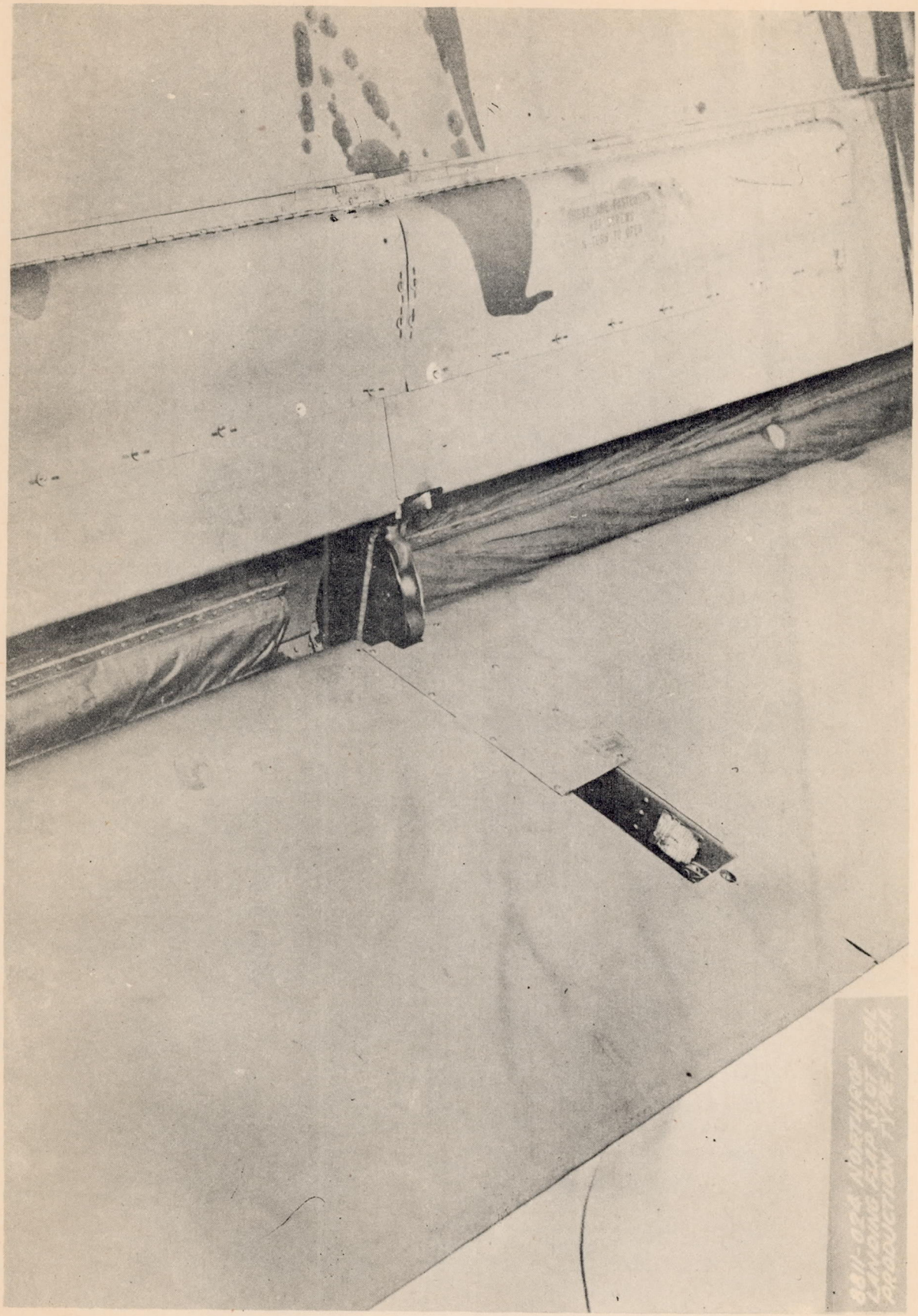


Figure 10b.- Photograph of fairing strip and flap seal on P-61 airplane.

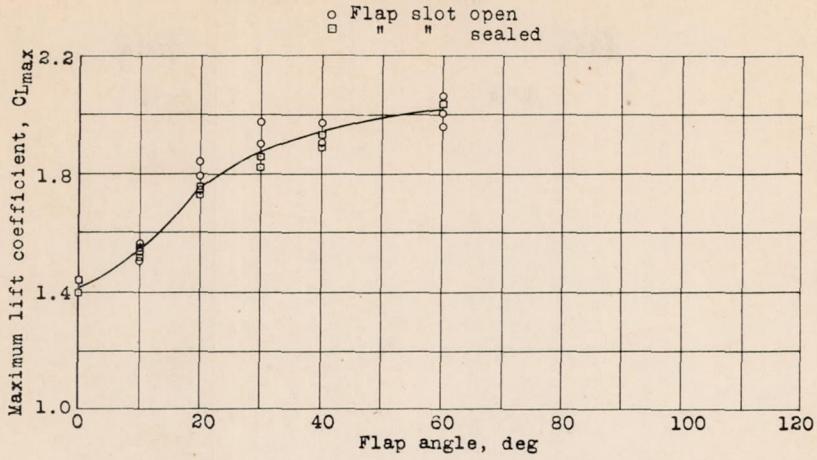


Figure 11.- Effect of flap seal on airplane maximum lift coefficient. Propeller windmilling.

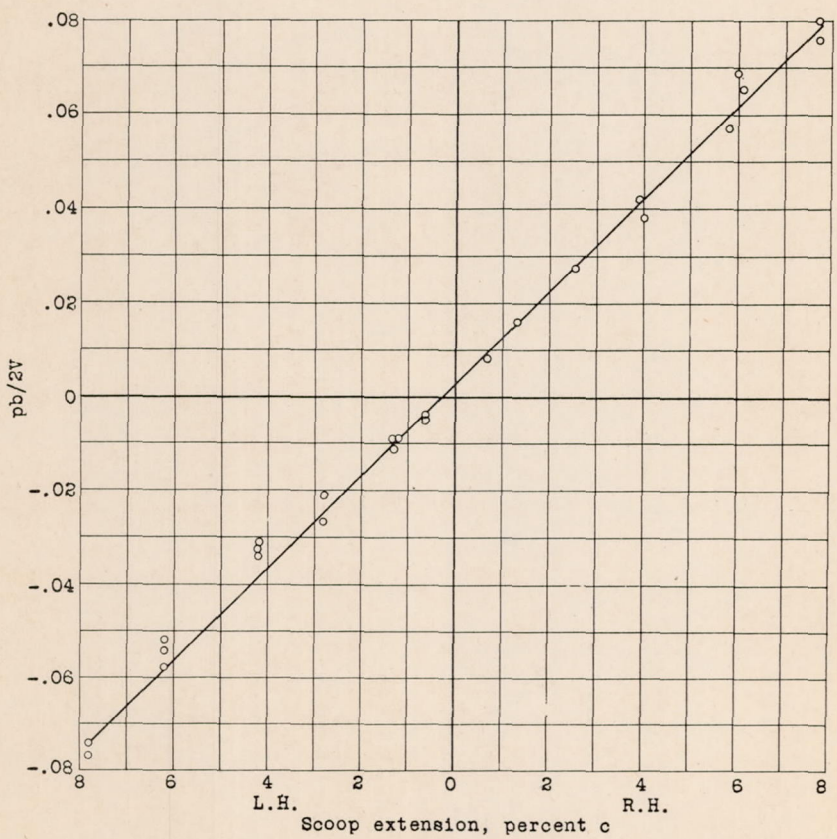


Figure 12.- Rate of roll at 135 mph, (C_L = .86) flaps and gear up, scoop slot closed, flight No. 31.

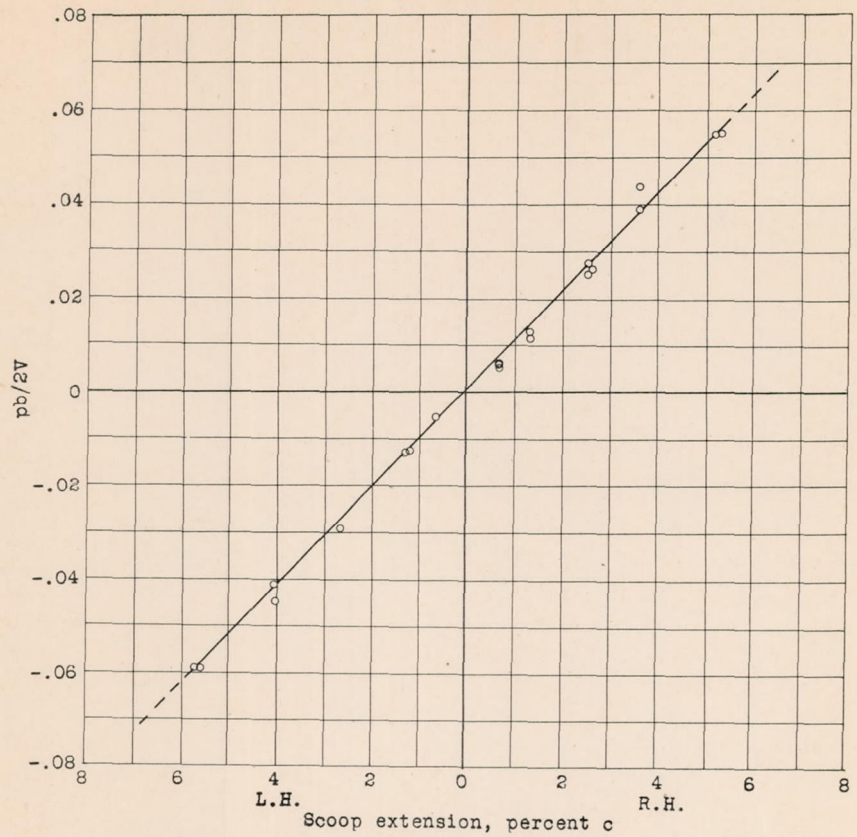


Figure 13.- Rate of roll at 285 mph, (C_L = .19) flaps and gear up, scoop slot closed, flight No. 31.

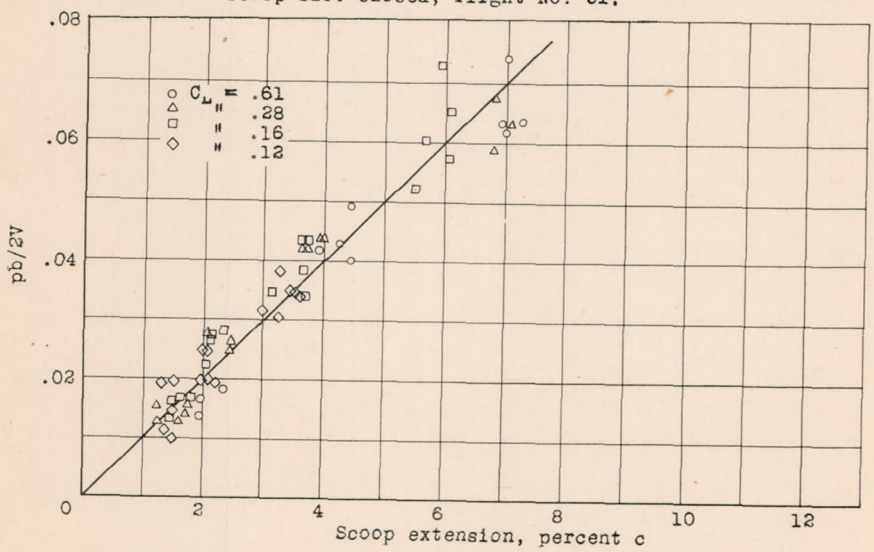


Figure 14.- Rate of roll flaps up, scoop slot closed, flight No. 53.

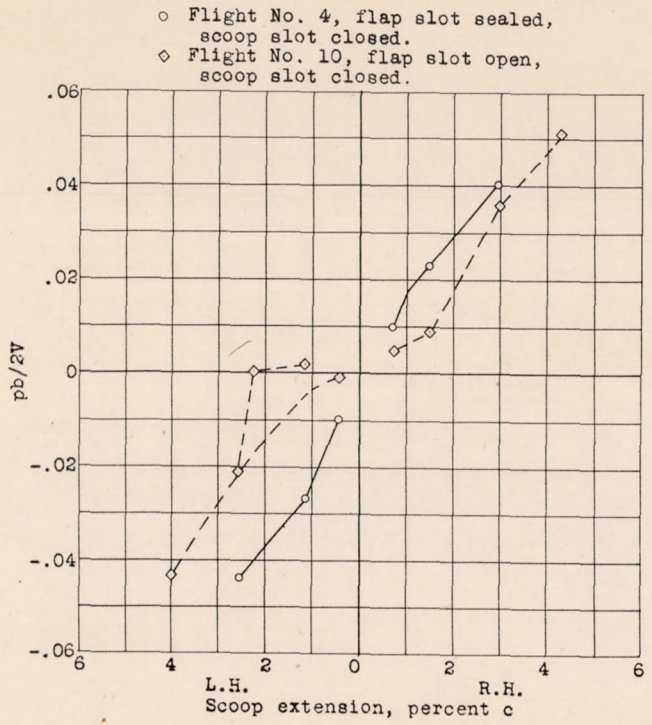


Figure 15.- Rate of roll at 100 mph, (C_L = 1.57) flaps and gear down.

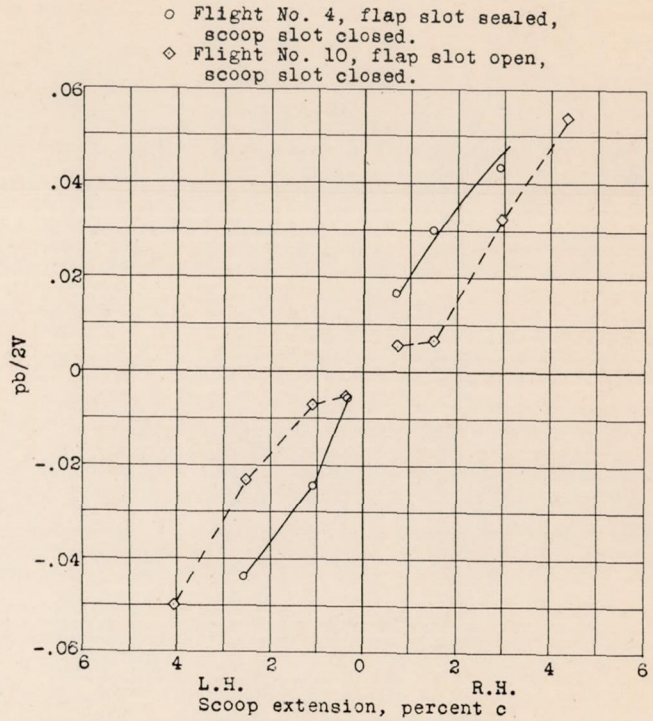


Figure 16.- Rate of roll at 160 mph, (C_L = .81) flaps and gear down.

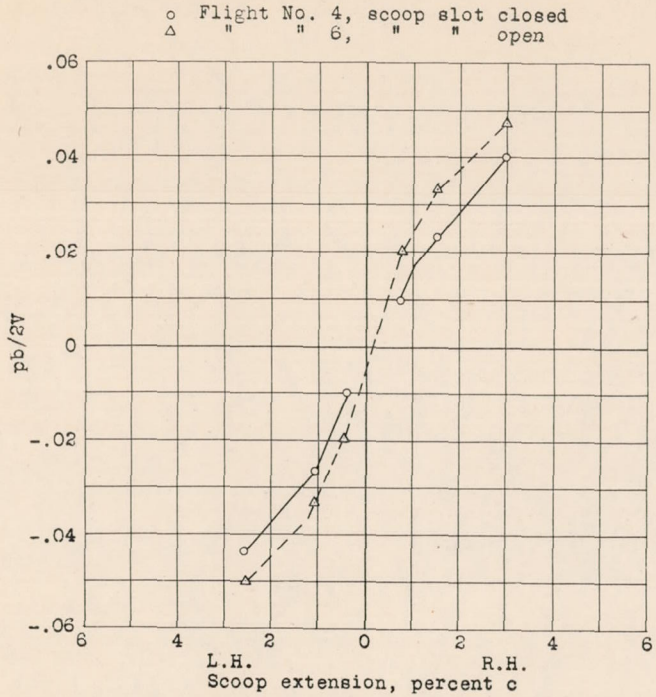


Figure 17.- Rate of roll at 100 mph, (C_L = 1.57) flaps and gear down, flap slot sealed.

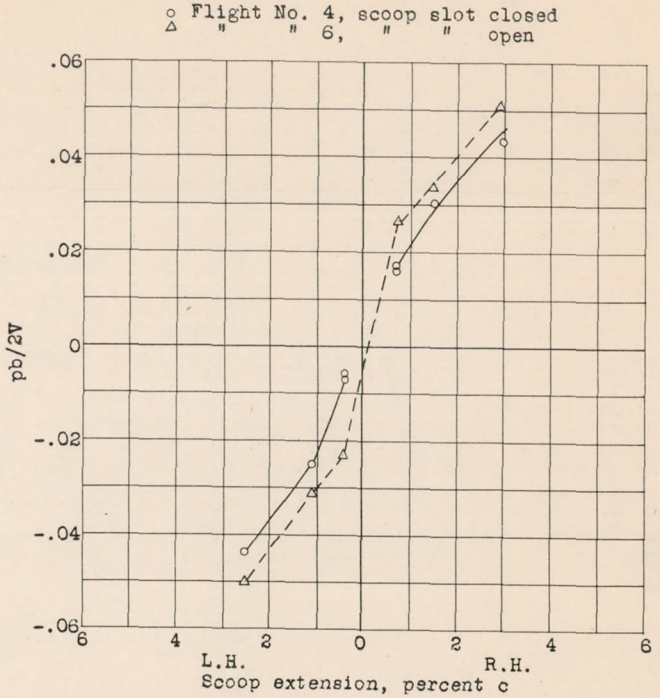


Figure 18.- Rate of roll at 160 mph, (C_L = .61) flaps and gear down, flap slot sealed.

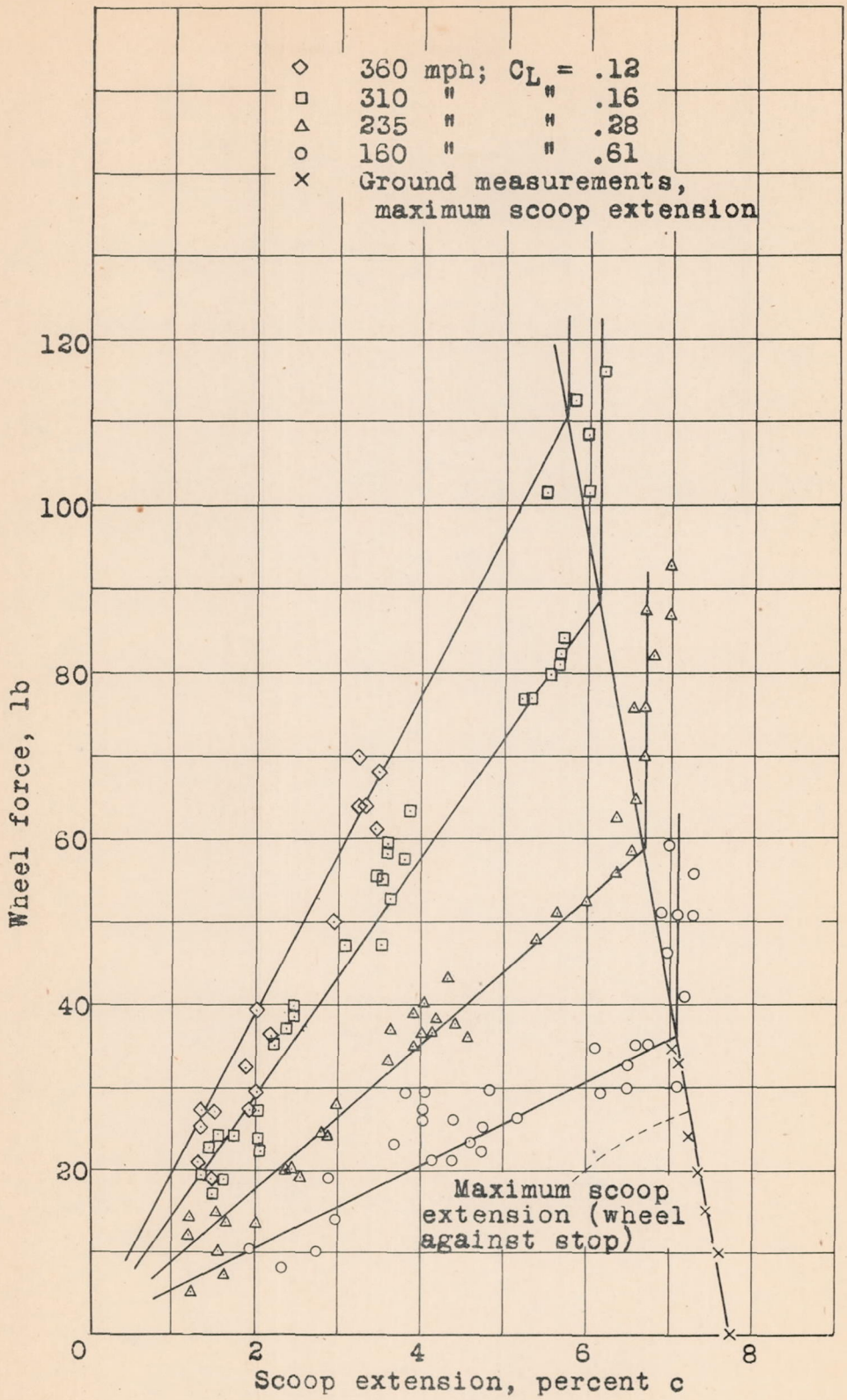


Figure 19.- Wheel force against scoop extension, flights 52, 53 and 56.